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Atmospheric Rivers (ARs):

A Global Approach for our Regional Interest

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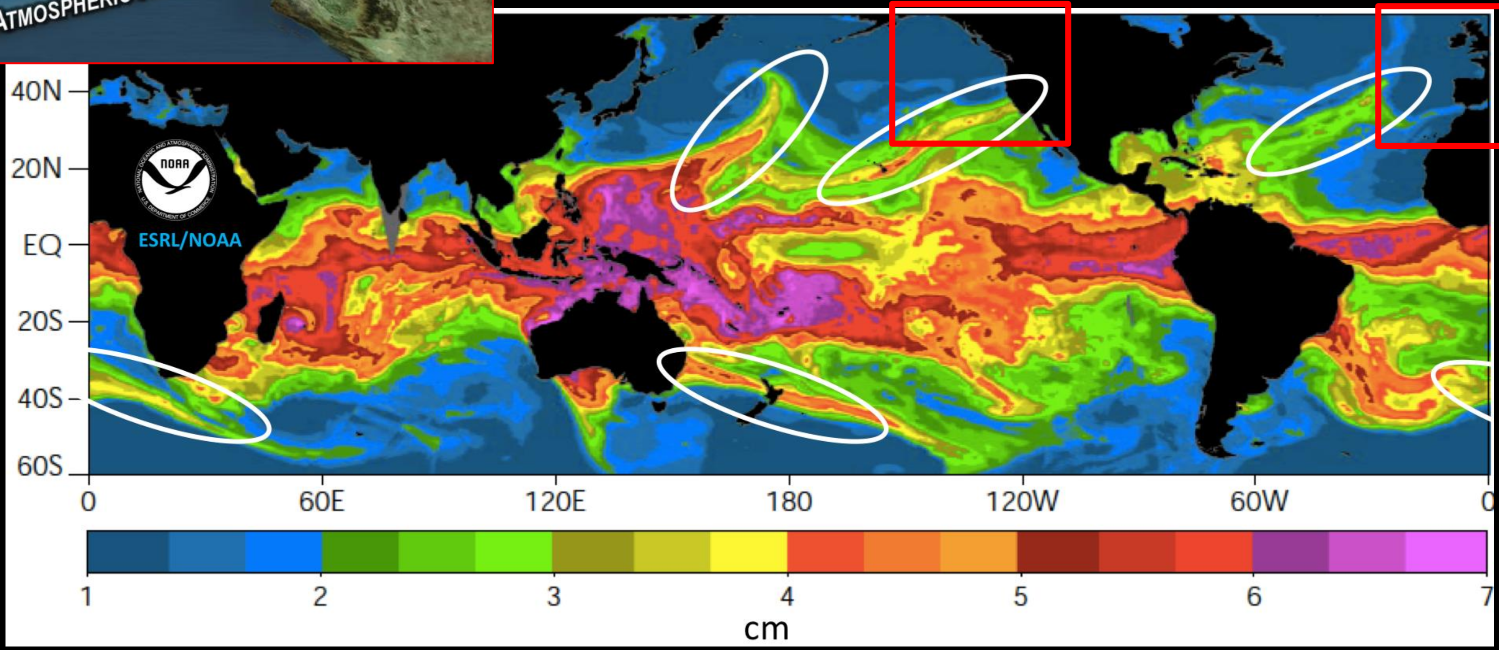
Pasadena, CA

With significant collaboration / support from the
Center for Western Weather and Water Extremes (M. Ralph et al.)
CA Department of Water Resources (J. Jones)
NASA Energy and Water Cycle Research Program (J. Entin)

Metropolitan Water District
March 28, 2018

Atmospheric Rivers (ARs)

SSM/I Integrated Water Content (IWV)



Most AR studies to date have been regionally focused on western N. America and western Europe.

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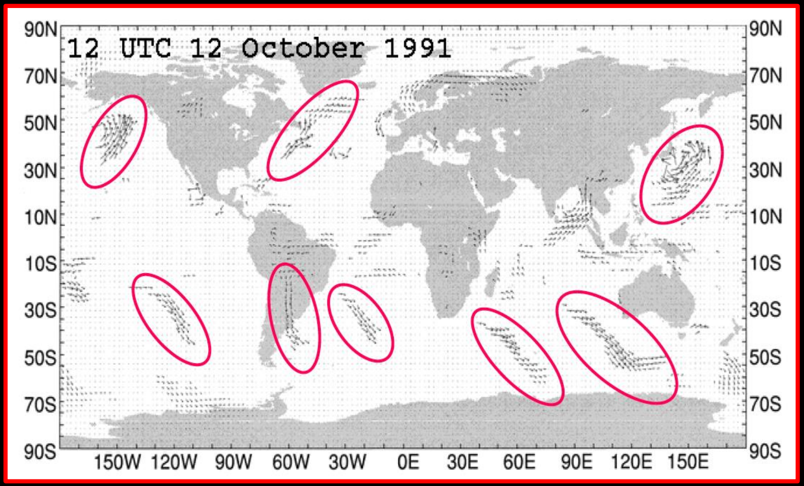
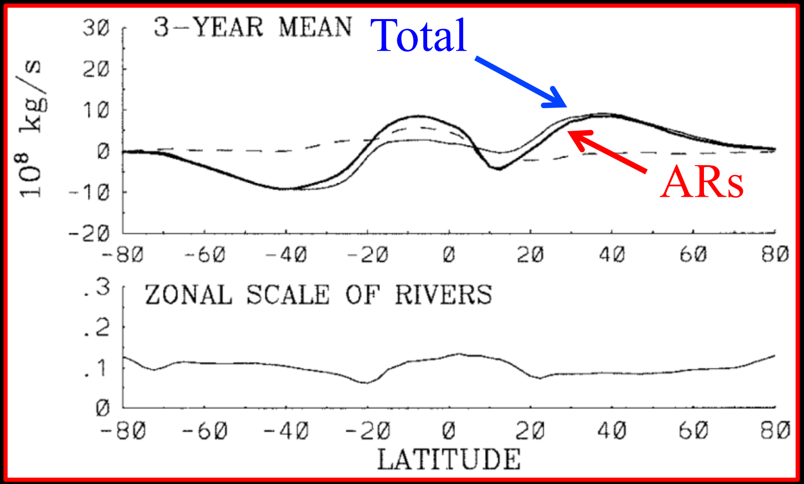
Origin of “Atmospheric Rivers”



Over 90% of poleward moisture transport at midlatitudes is by ARs that take up only ~10% of the zonal circumference; Zhu and Newell (1998)



These extreme storms influence global water and energy budgets, and thus shape Earth’s climate.

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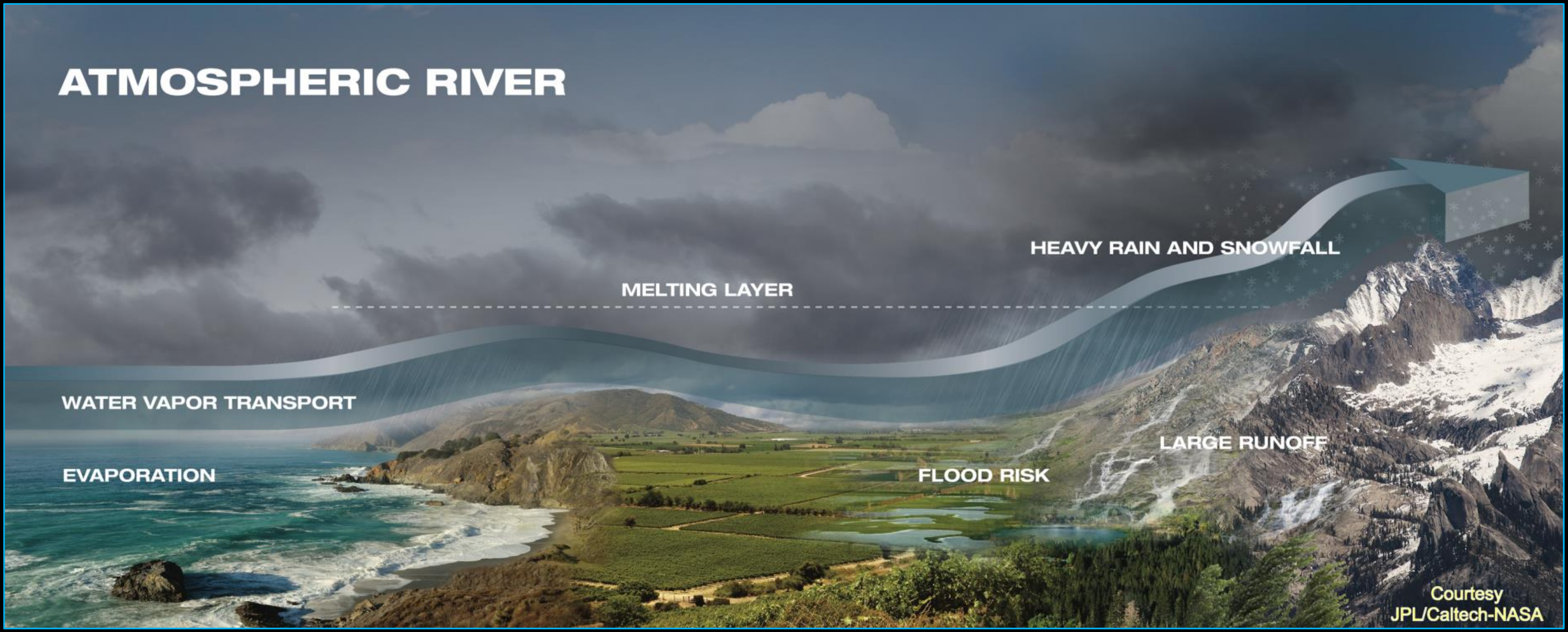
AR Landfall Impacts



Account for ~40% of California's annual water supply in a few storms
Account for most flooding events on U.S. West coast

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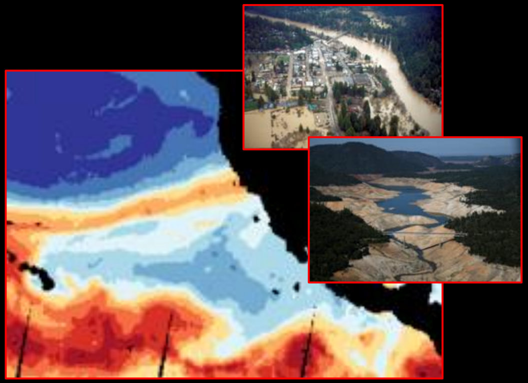
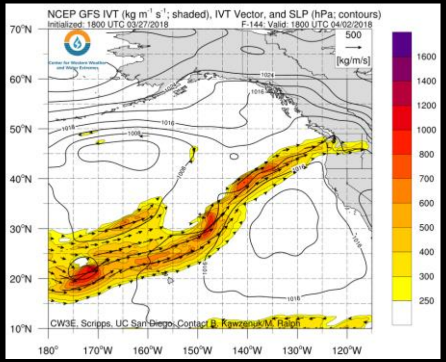
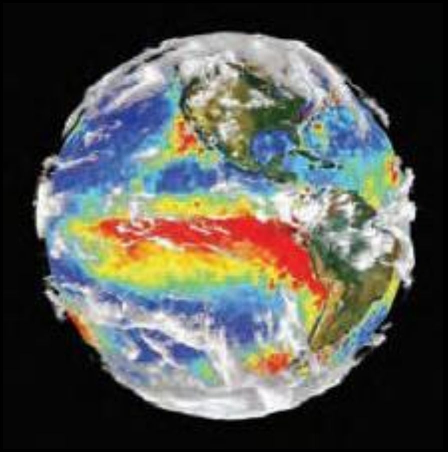
Regional Concerns vs Global Approach



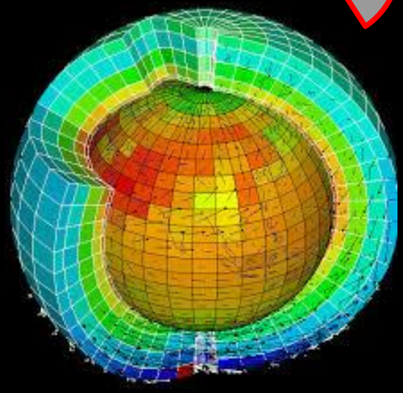
Manage California Water Resources & Flood Hazards



Management Aided by Accurate Weather & Climate Predictions



Modern Weather & Climate Prediction is a Global Consideration

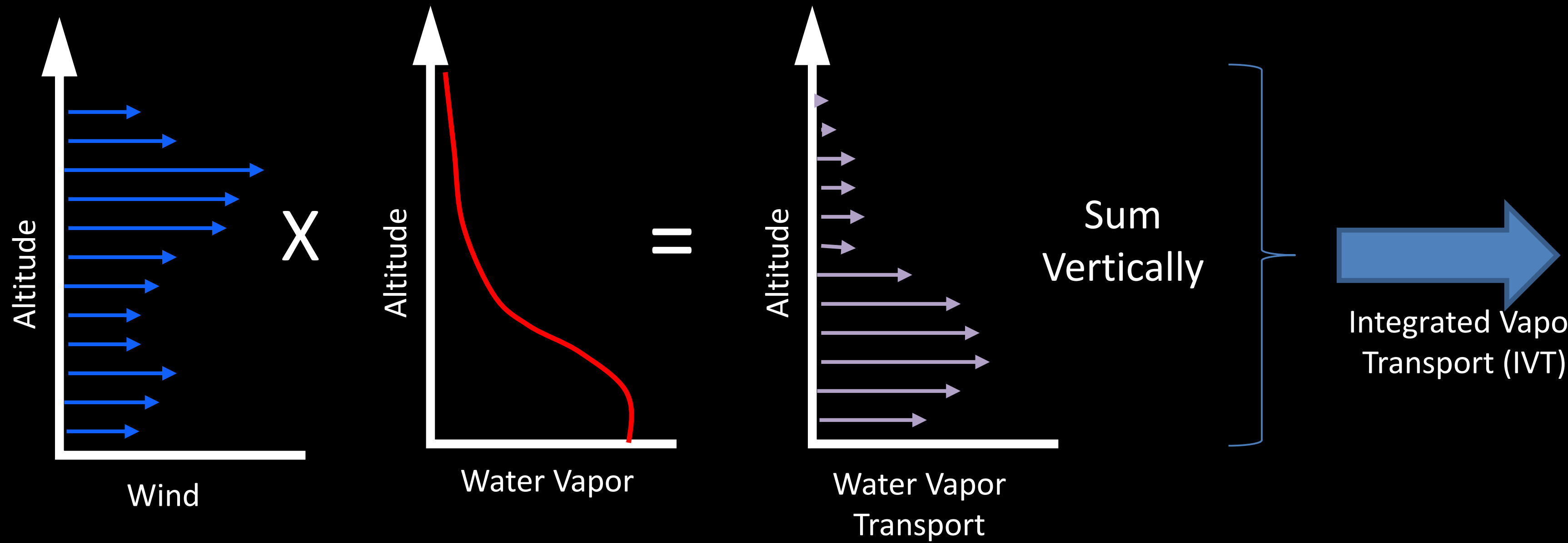


Outline

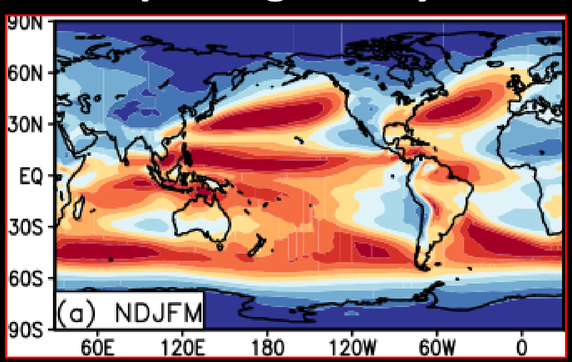
1. **Global AR Considerations**
   1. Detection
   2. Characteristics
   3. Impacts
   4. Weather Predictions
   5. Climate Projections
2. **Regional AR Interests**
   1. Experimental Subseasonal (i.e. week 3) Predictions

Global AR Detection

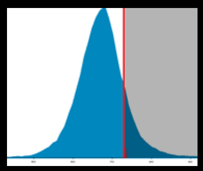
I. Compute IVT



II. Map IVT globally



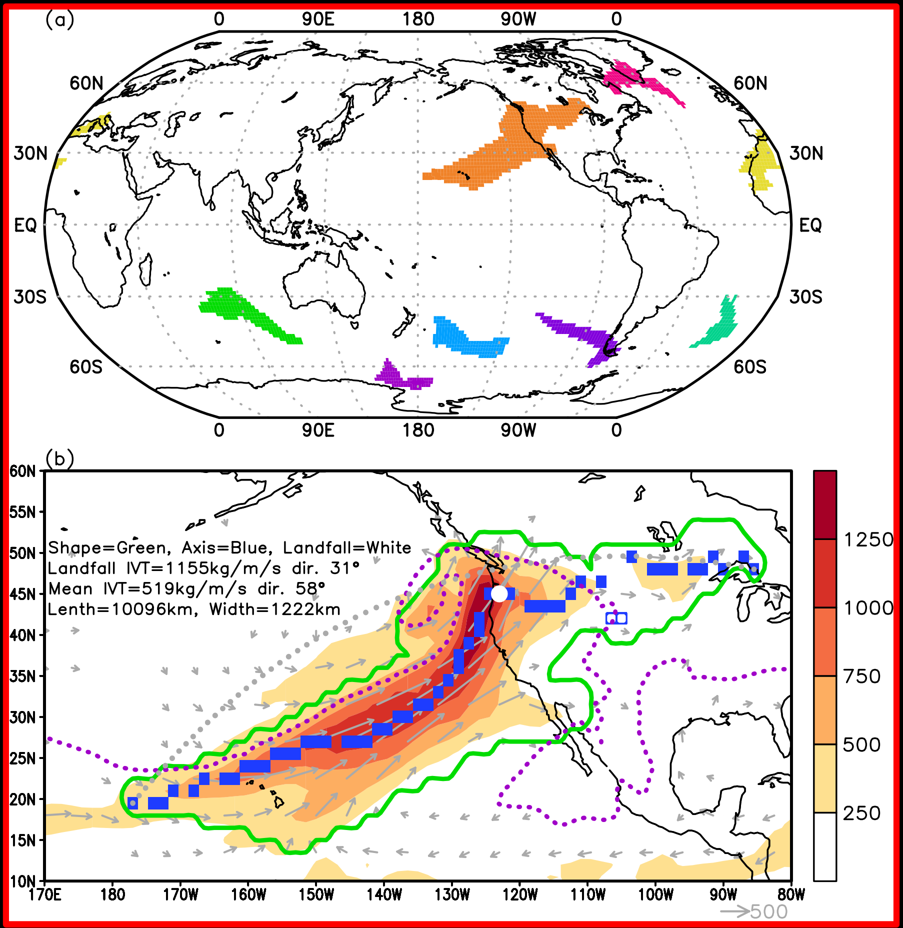
III. Apply AR Criteria



- IVT > 85th percentile
- Look for contiguous areas
- Length > 2000 km
- Length/Width > 2

Gives Long, Narrow Extreme Moisture Transports i.e. Rivers

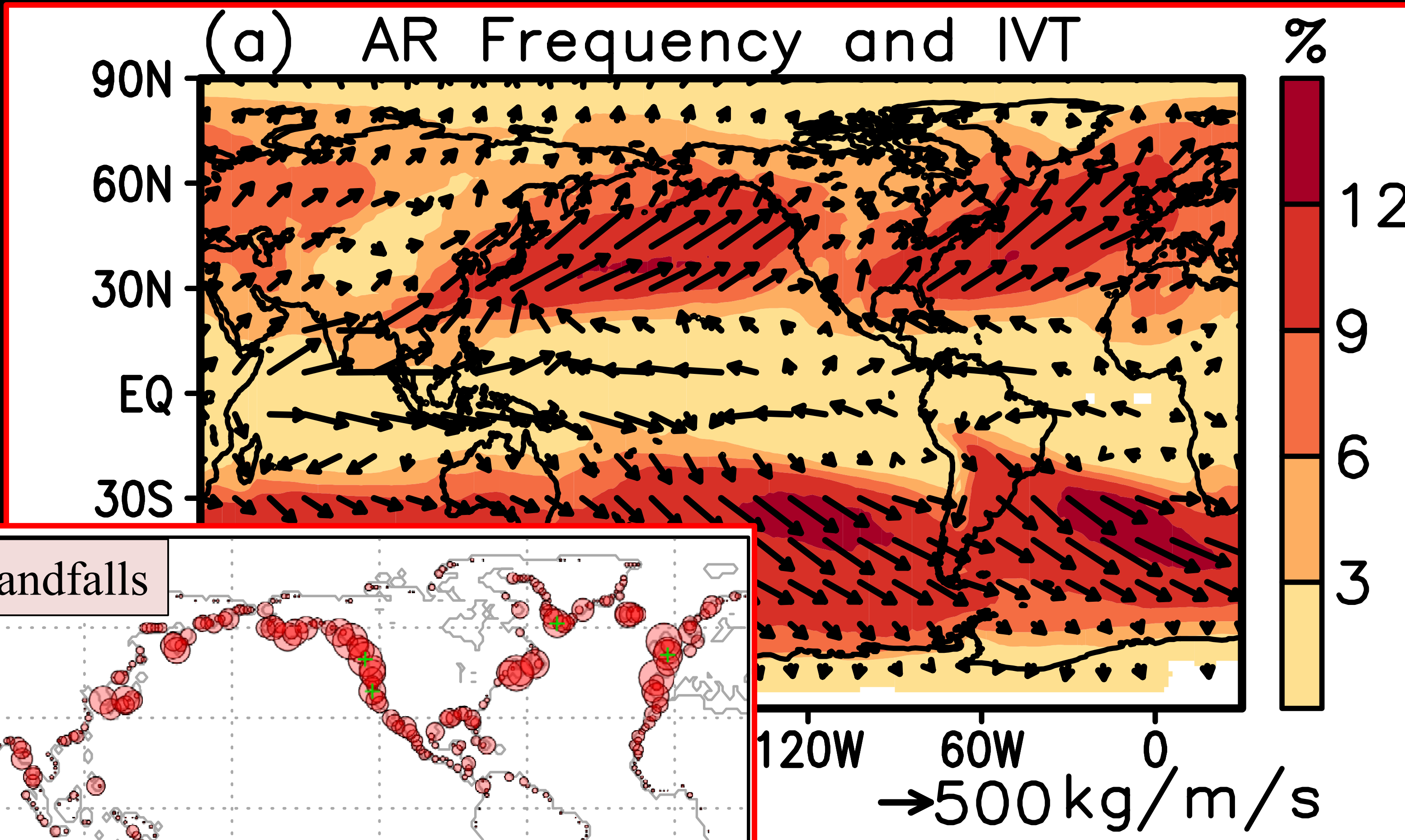
Global AR Detection

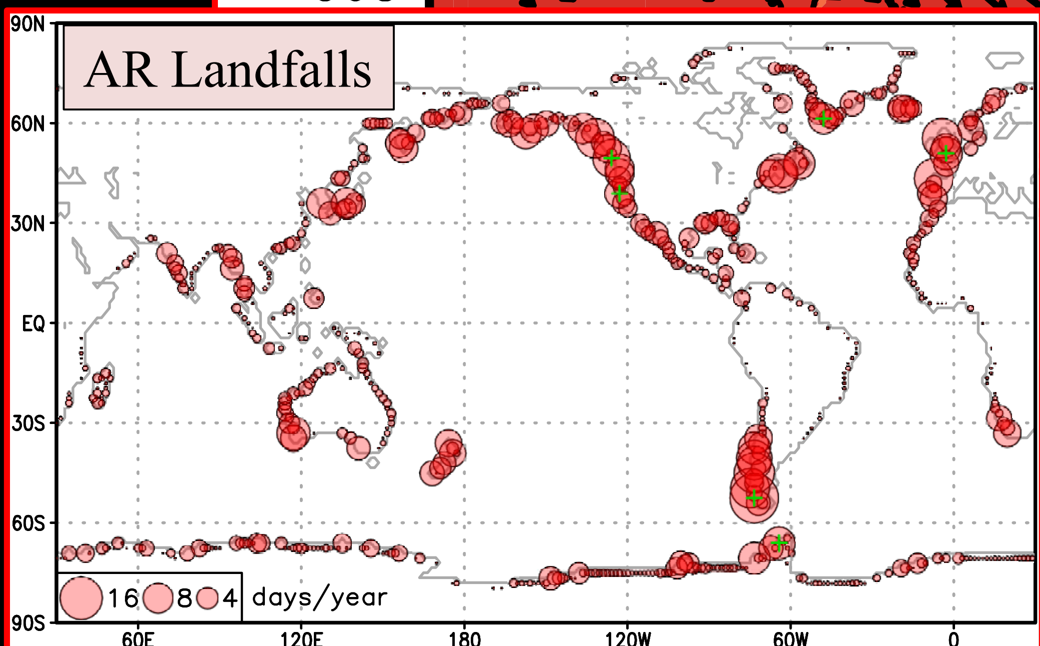


Guan and Waliser (2015)

- AR detection applied to global "reanalysis" datasets (e.g., ERA-I, MERRA-2)
- ~30 year records, with AR maps every 6 hours
- Code and databases available.
- Developed for global studies – analysis, modeling, prediction, etc.

Global AR Characteristics

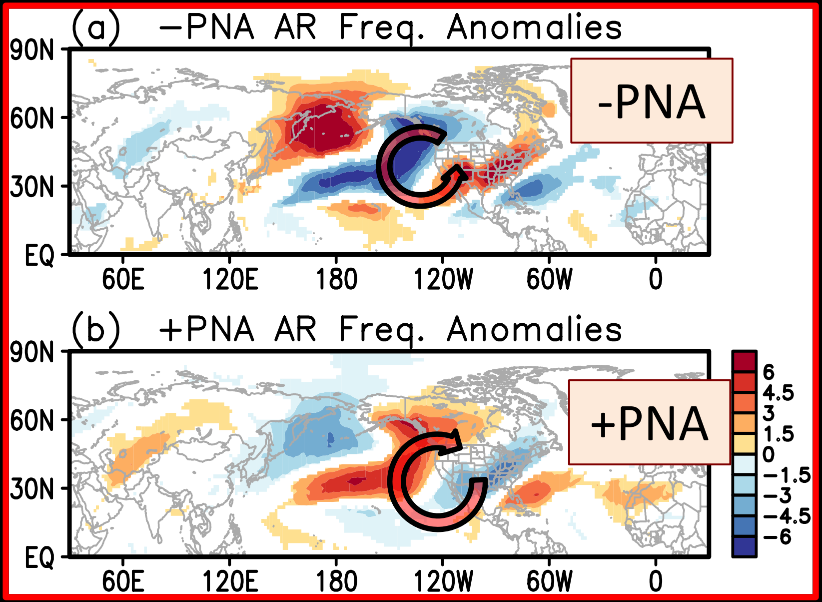




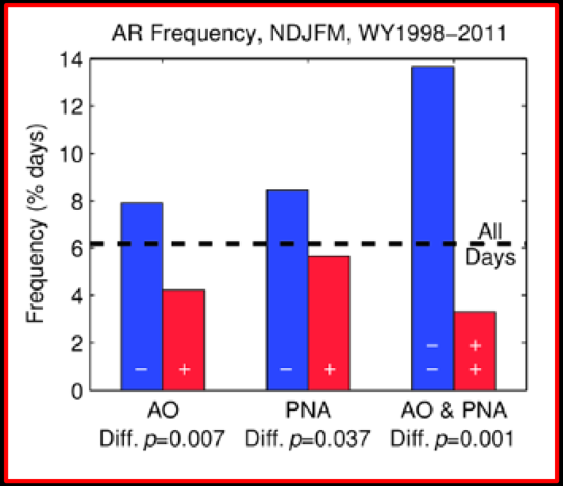
Guan and Waliser (2015)

Climate Patterns and ARs

Pacific-North American (PNA)



Climate patterns, such as PNA, affect the frequency of ARs

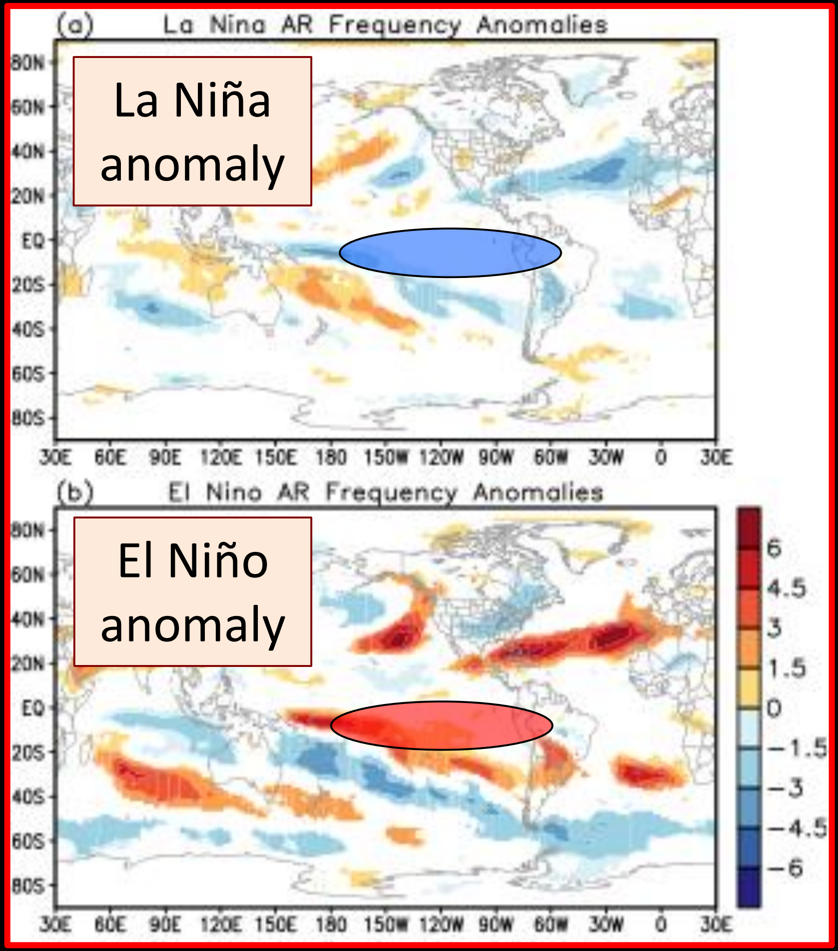


2010/2011 Winter in California

- Largest total seasonal snow in previous 14 Years (~170% of normal)
- Largest # of AR days (twice normal)
- –PNA and –AO Conditions

Guan et al. 2013

Climate Patterns and ARs



El Nino Southern Oscillation (ENSO)

Impacts AR Frequency Across the Globe

Longer-lead predictions of ARs may be enabled by these slowly evolving "climate" patterns

Guan and Waliser (2015)

AR Extremes & Global Impacts

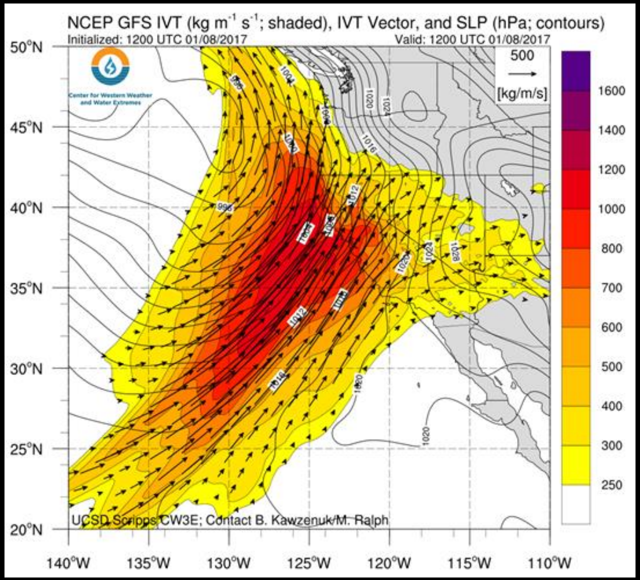


Image from M. Ralph/CW3E/SIO/UCSD

- A strong Atmospheric River (AR) made landfall over the U.S. West Coast on 8-9 January 2017.
- A number of locations experienced over 12 inches of precipitation over 3 days, and were exposed to extreme wind conditions.
- The extreme storm conditions resulted in the demise of the "Tunnel Tree", a giant sequoia in Calaveras Big Trees State Park, California

Pioneer Cabin Tree, also known as the "Tunnel Tree", a giant sequoia in Calaveras Big Trees State Park, CA

Slide developed by D. Waliser (JPL), M. Dettinger (USGS) & M. Ralph (CW3E/UCSD)

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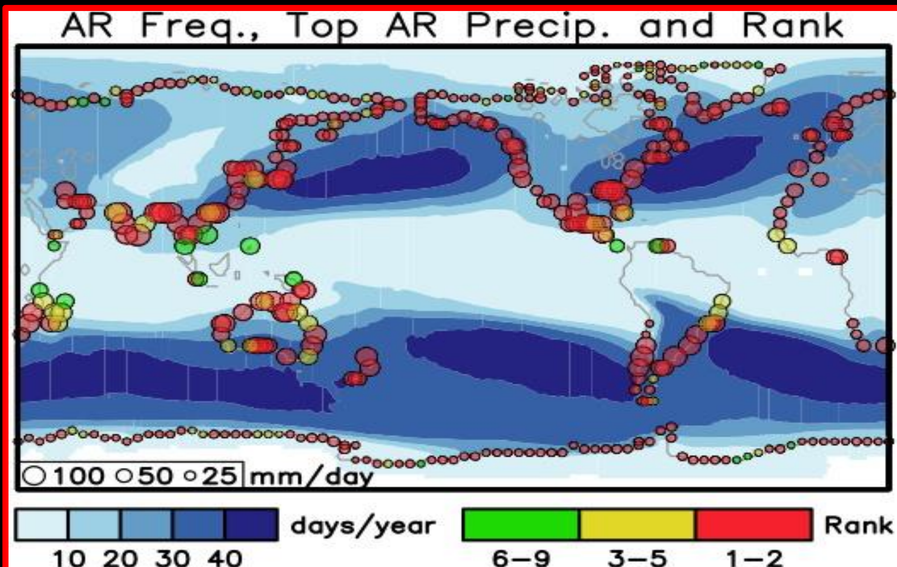
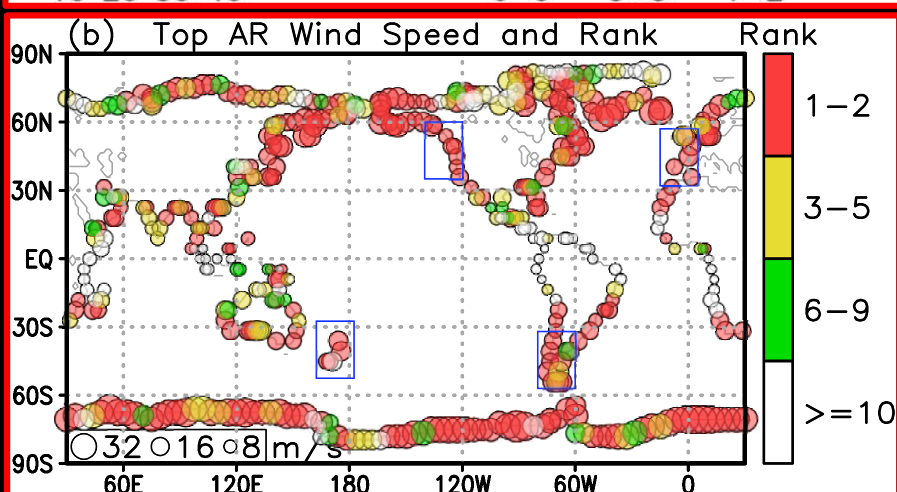
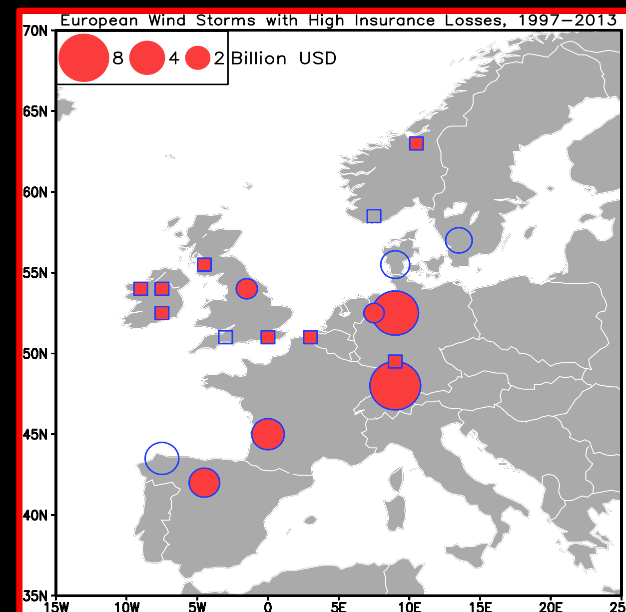
AR Extremes & Global Impacts

Wind & Precipitation





Circle color (size) indicates the rank (speed) of 10 m wind extremes that are connected to an AR considering all 6-hourly ECWMF surface wind values from 1997-2014.



Of 19 damaging wind storms with insurance losses in $B US over Europe from 1997-2013, 14 (filled) were associated with ARs. Circle size indicates size of $ loss; squares are less than $1B.

Waliser & Guan (2017)

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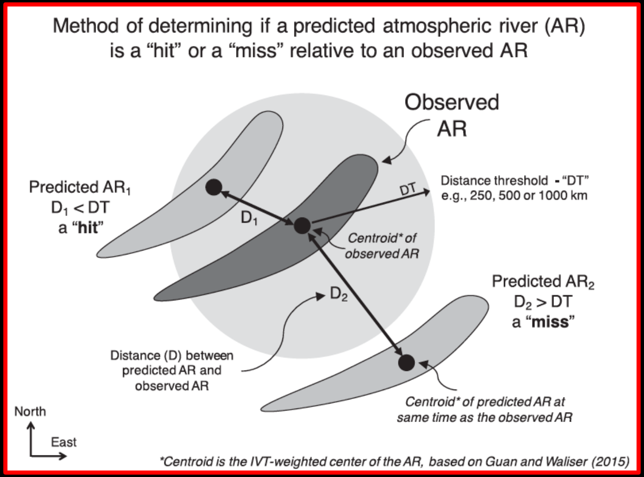
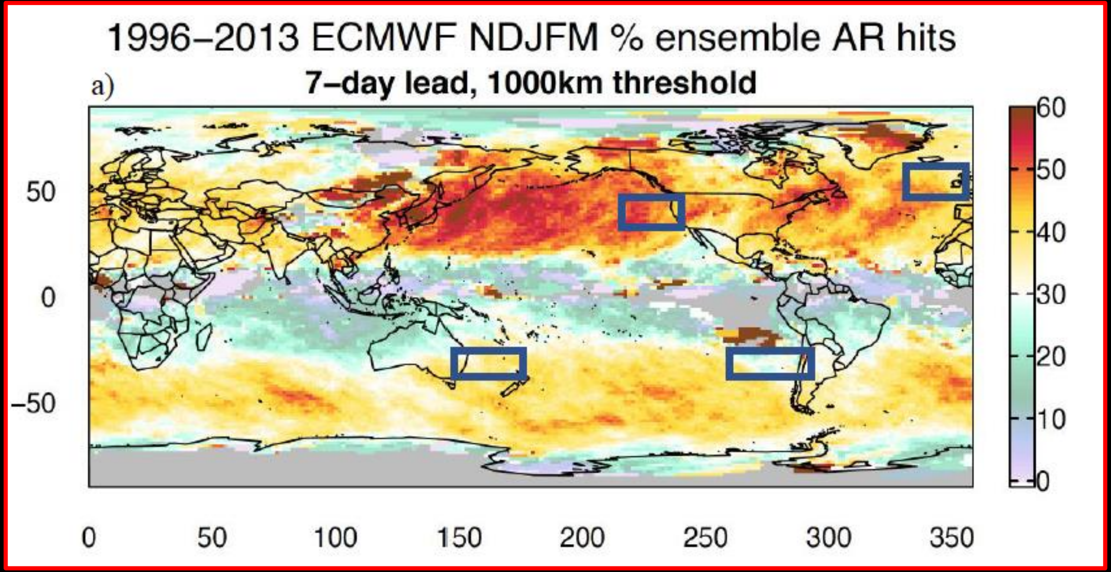
Predicting AR Events



How well do our global NWP models – ECMWF in this case - predict AR occurrence & position?

ECMWF Subseasonal to Seasonal (S2S) hindcasts include twice-per-week, 11 member ensembles, from 1996-2013.

Courtesy WCRP/WWRP S2S Project



DeFlorio, Waliser, Guan, Lavers, Ralph, Vitart (2018)

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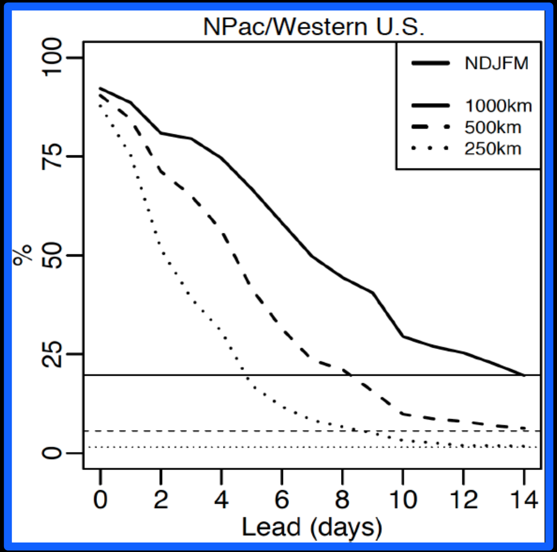
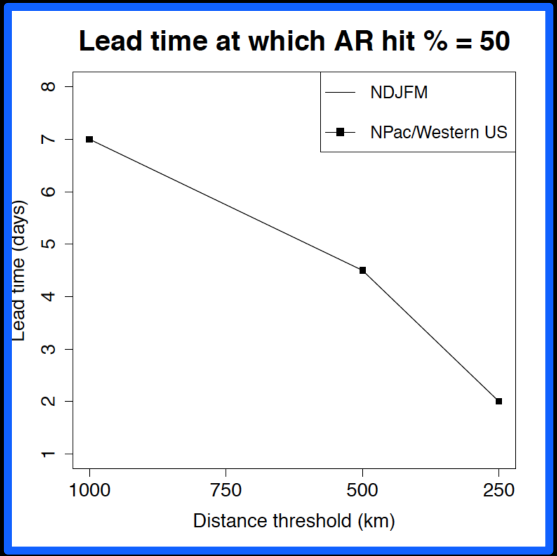
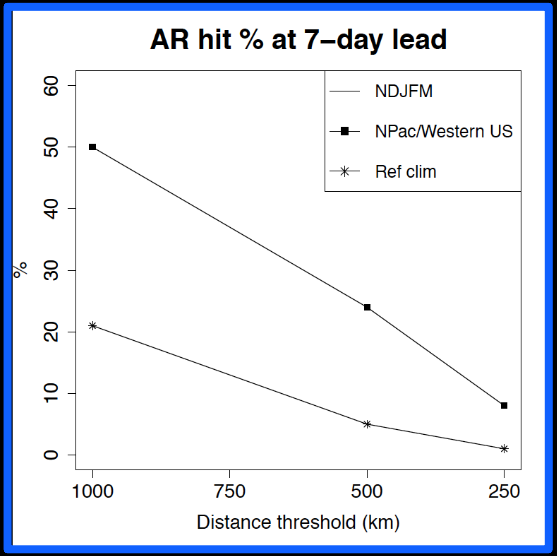
Predicting AR Events



Decision Support Tradeoffs





DeFlorio, Waliser, Guan, Lavers, Ralph, Vitart (2018)

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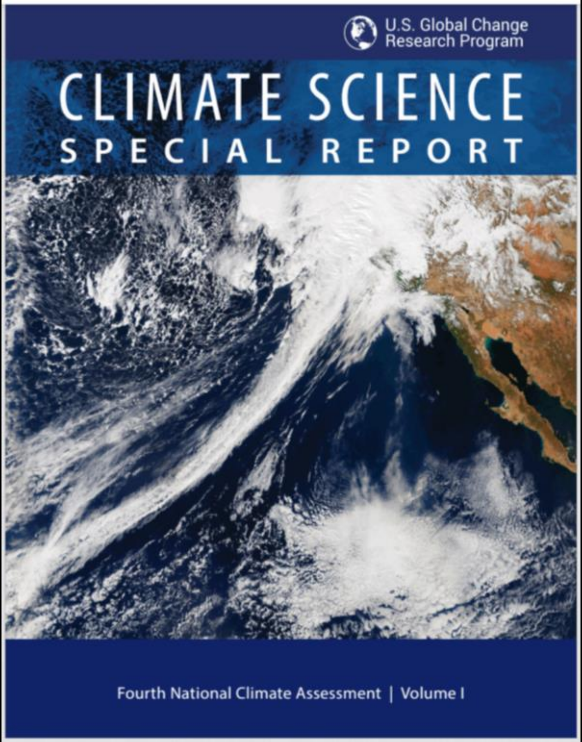
Climate Change & ARs

Previous Studies

Publication	Historical Period	Projection Period	Geographic Region	AR Freq (± %)	AR IVT (± %)
Dettinger (2011)	1961- 2000	2046 - 2065; 2081 - 2100	CA Coast	+ 30	+ 10
Pierce et al. (2013)	1985 - 1994	2060s	CA Coast	+ 25 - 100	--
Warner et al. (2015)	1970 – 1999	2070 - 2099	US West Coast	+ 230 - 290	+ 30
Payne and Magnusdottir (2015)	1980 - 2005	2070 -2100	US West Coast	+ 23 - 35	--
Gao et al. (2015)	1975 - 2004	2070 - 2099	US West Coast	+ 50 - 600	--
Hagos et al. (2016)	1920 - 2005	2006 - 2099	US West Coast	+ 35	--
Shields et al. (2016)	1960 - 2005	2055 - 2100	US West Coast	+ 8	--
Espinoza et al. (2018, current study)	1979 - 2002	2073 - 2096	US West Coast	+ 45	+ 30
Lavers et al. (2013)	1980 - 2005	2074 - 2099	W. Europe	+ 50 - 100	--
Gao et al. (2016)	1975 - 2004	2070 - 2099	W. Europe	+ 127 - 275	+20 - 50
Ramos et al. (2016)	1980 - 2005	2074 - 2099	Europe	+100 - 300	+ 30
Shields et al. (2016)	1960 - 2005	2055 - 2100	North Atlantic	+ 4	--
Espinoza et al. (2018, current study)	1979- 2002	2073-2096	W. Europe	+ 60	+ 30

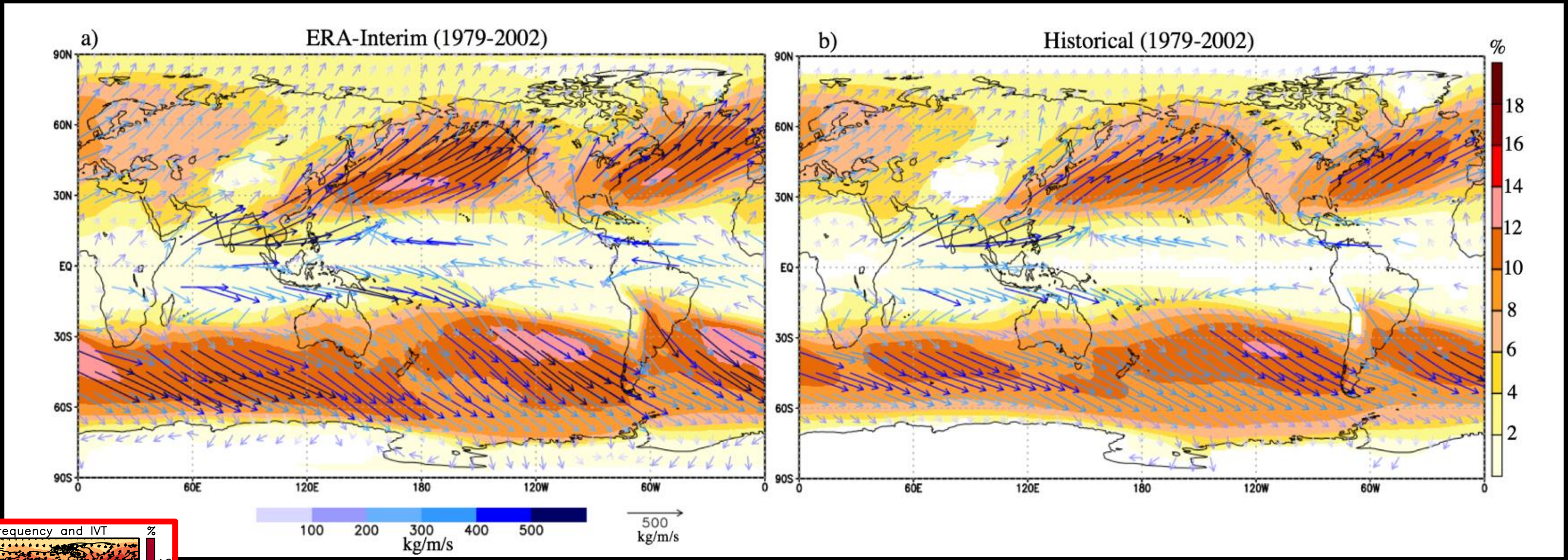


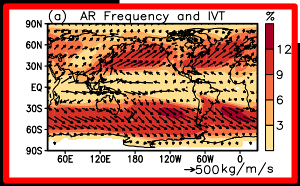
- *No Global Studies*
- *No way to compare UK & US, different models, methods and algorithms*
- *What about outside UK & US?*

Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

Climate Change & ARs

AR Frequency, Size & Transport: 21 CMIP5 Models





Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

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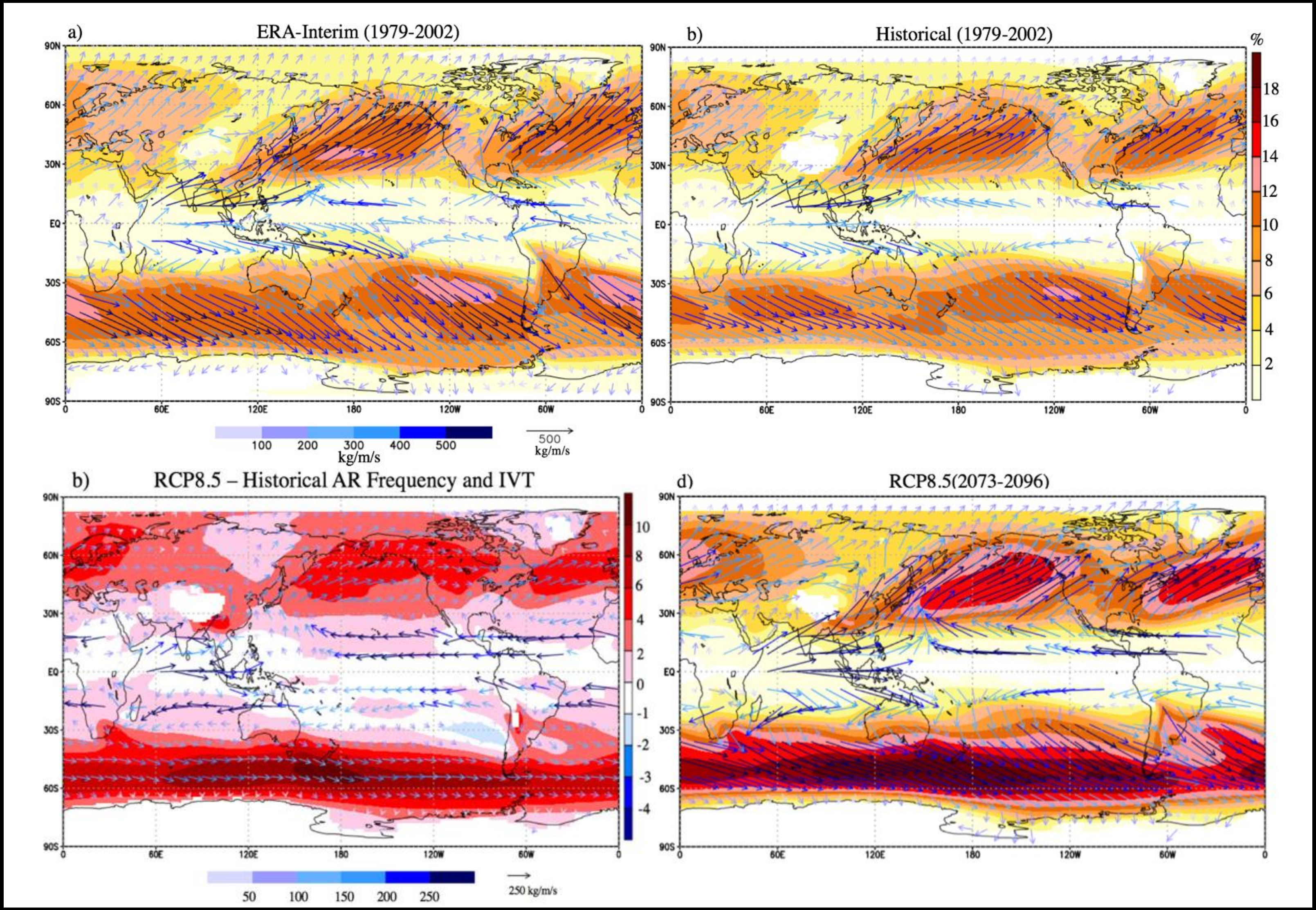
Climate Change & ARs

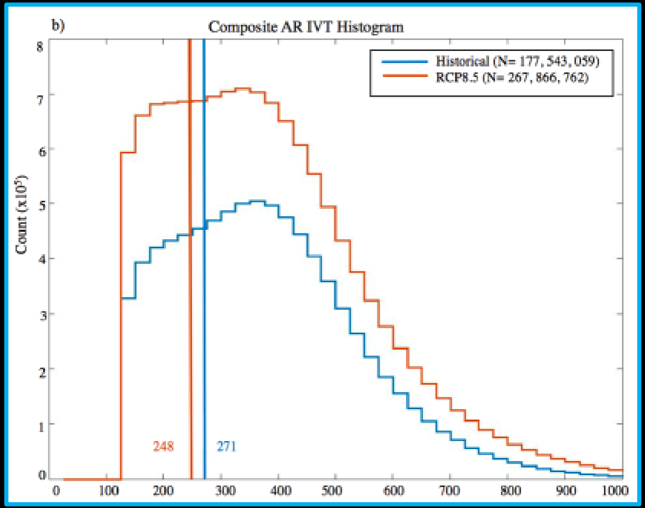
AR Frequency, Size & Transport: 21 CMIP5 Models



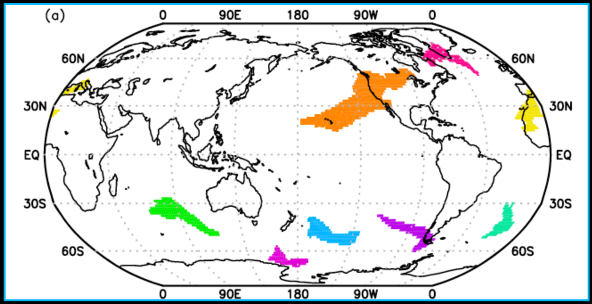
Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

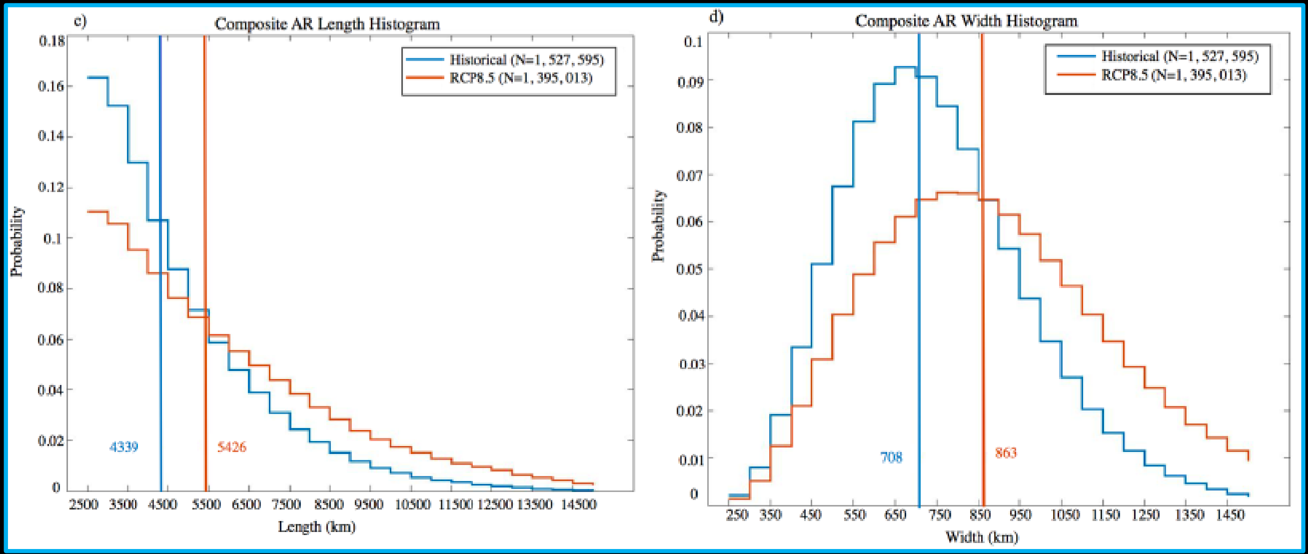
Climate Change & ARs

AR Frequency, Size & Transport: 21 CMIP5 Models



AR conditions vs AR Events





Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

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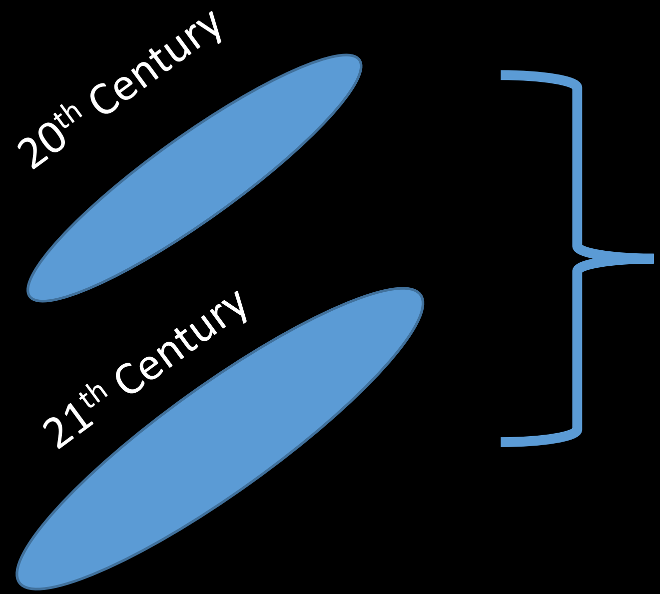
Climate Change & ARs



Changes in ARs

About 25% longer
About 25% wider
About 10% fewer

AR Conditions = Number ARs * Length * Width

About 40% Increase in AR Conditions

Occurrence of extreme IVT values within ARs ~double.

Espinoza, Waliser, Guan, Lavers, Ralph (2018, submitted w/ revisions)

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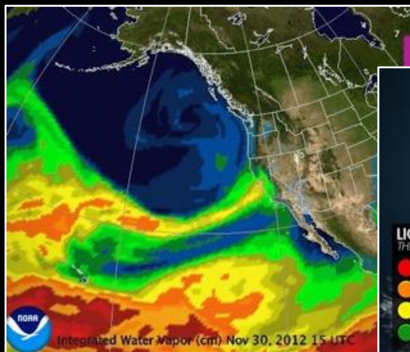
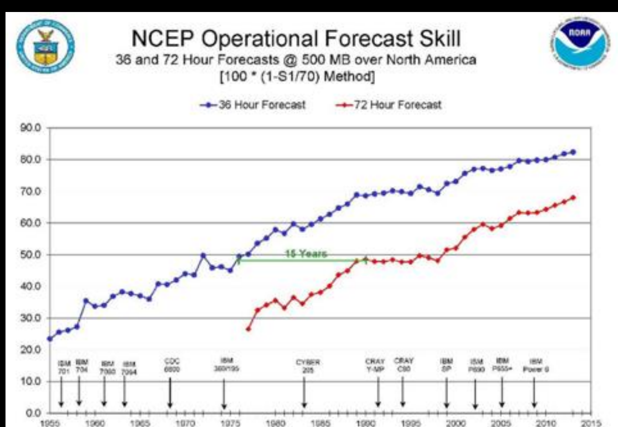
Weather Forecasts

0-14 Days

e.g. Atmospheric Rivers

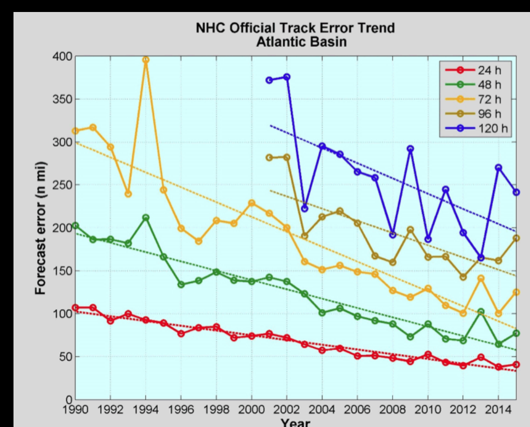


Forecast Skill Increasing



General Weather Patterns

Forecast Errors Diminishing



Hurricanes

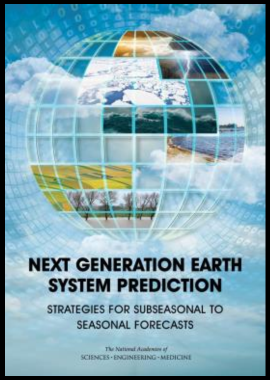
More/Better Observations
Improved Models
More Computing Power

… cold spells, hurricanes, heat waves, thunderstorms/tornados, nor'easters, santa ana winds, etc

Forecast Lead Times

- Weather — 0-14 Days
- **Subseasonal — 2-12 Weeks**
- **Seasonal — 3-12 Months**
- Interannual — 1 year - Decade
- Climate — Decades - Centuries

Subseasonal to Seasonal (S2S)
2 weeks -12 months



2016 NAS Report

p.s. "subseasonal" aka "intraseasonal"

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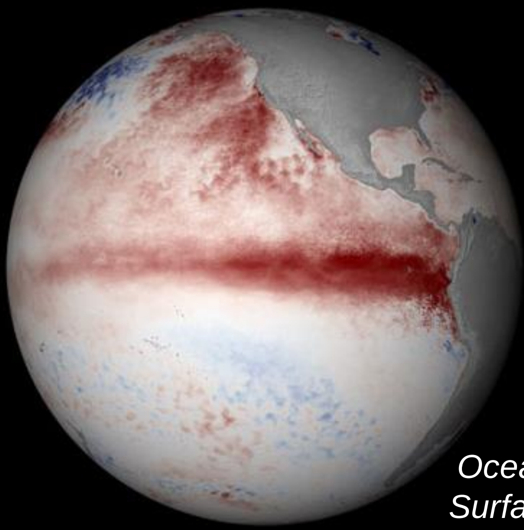
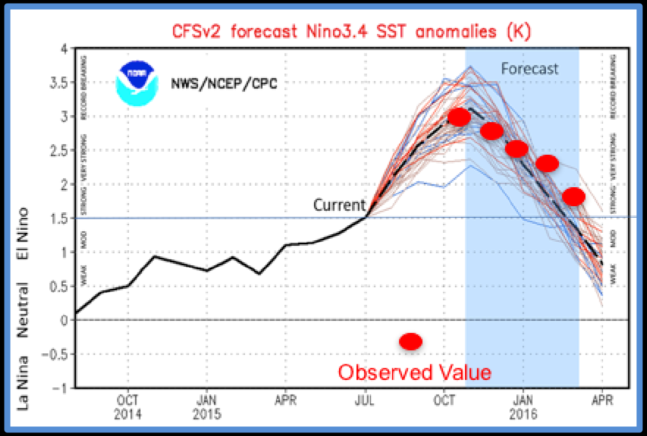
S2S: El Nino – La Nina

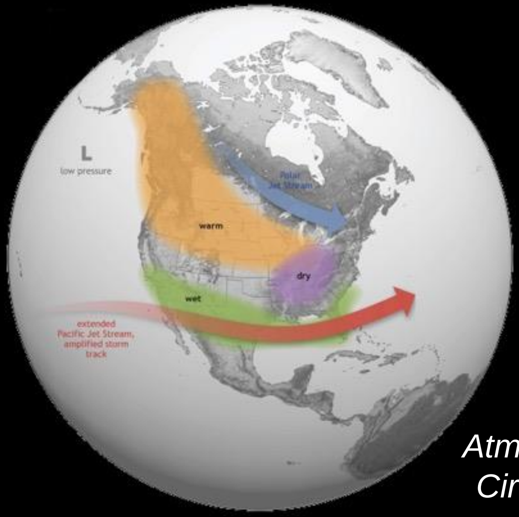
LifeCycle ~Months



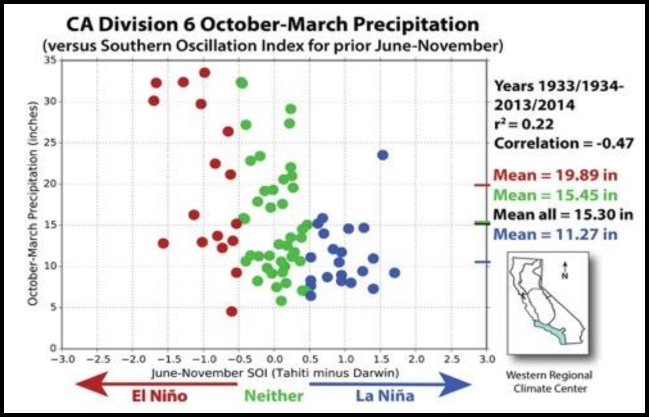
Ocean Surface Temperature



Tropical SST – Capabilities to Predict



Atmospheric Circulation



Extra-tropical Impacts – Difficult/Still Learning

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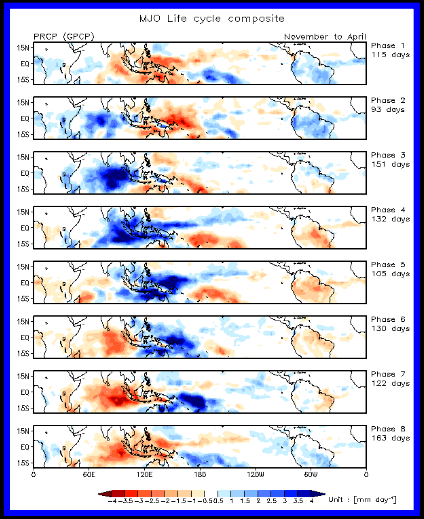
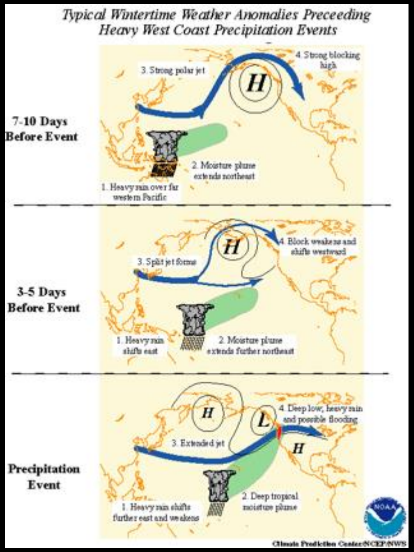
S2S: **Madden-Julian Oscillation**

LifeCycle ~Weeks

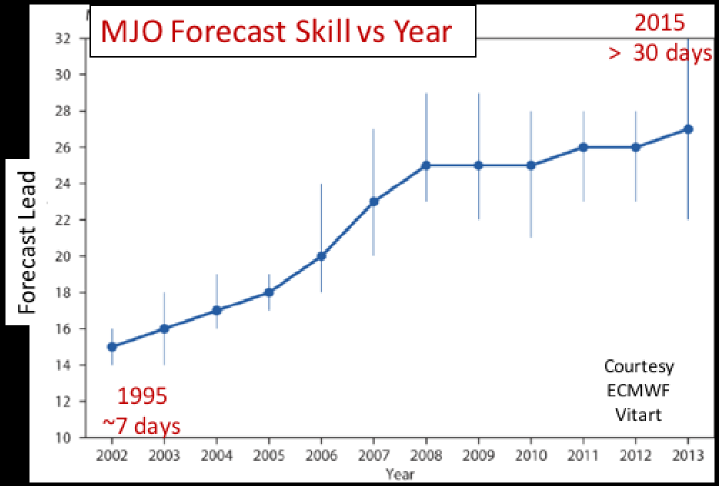


40-50
Days

Tropical Precipitation & Circulation



Extra-tropical Atmospheric Circulation



Tropical MJO – Skill out to 3-4 Weeks

Extra-tropical Impacts – Difficult/Still Learning

More/Better Observations
Improved Models
More Computing Power

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Subseasonal AR Forecasts

Experimental - *Week 3*

Experimental Atmospheric River Forecast*

Issued on Monday, March 12, 2018

Contents:

Slides 1 and 2: "Weather" - Typical presentation of US west coast weather/precipitation forecast over lead times of 1 to 14 days considering only the likelihood of an atmospheric river (AR) occurring on a given forecast day. *Novelty – a weather forecast presented only in terms of AR likelihood.*

Slides 3 and 4: "Subseasonal" - US west coast weather/precipitation forecast for week 3 considering the likelihood of an atmospheric river occurring in the given forecast week.
Novelty – as above, but also specifically for week 3, an extended/long-range or "subseasonal" prediction

**This is an experimental activity for the 2017-18 and 2018-19 winters. Methodologies and hindcast skill are documented in DeFlorio et al. (2018a,b). Further validation of the real-time forecast results is required and underway. This phase of the research includes gathering stakeholder input on the presentation of information – feedback is welcome.*

POC: Michael J. DeFlorio (michael.deflorio@jpl.nasa.gov)

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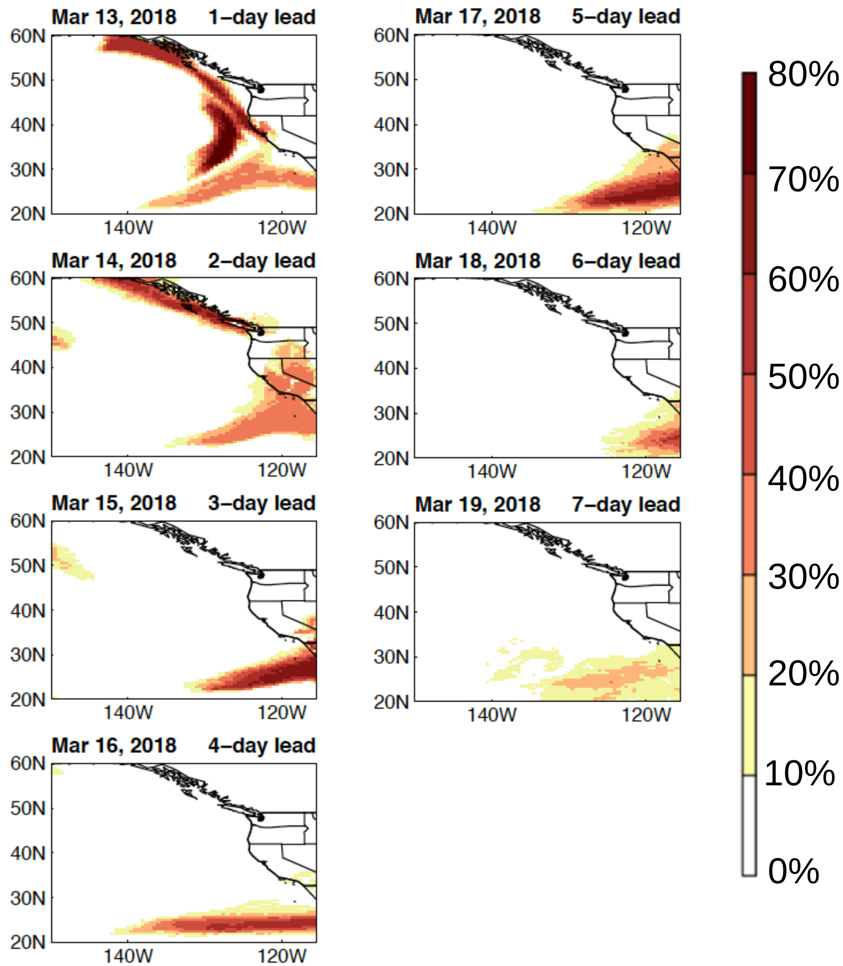
EXPERIMENTAL AR FORECAST

March 12, 2018 forecast: probability of AR occurrence during week-1



Week-1

(1-day to 7-day lead)

Experimental AR forecast issued on Monday, March 12, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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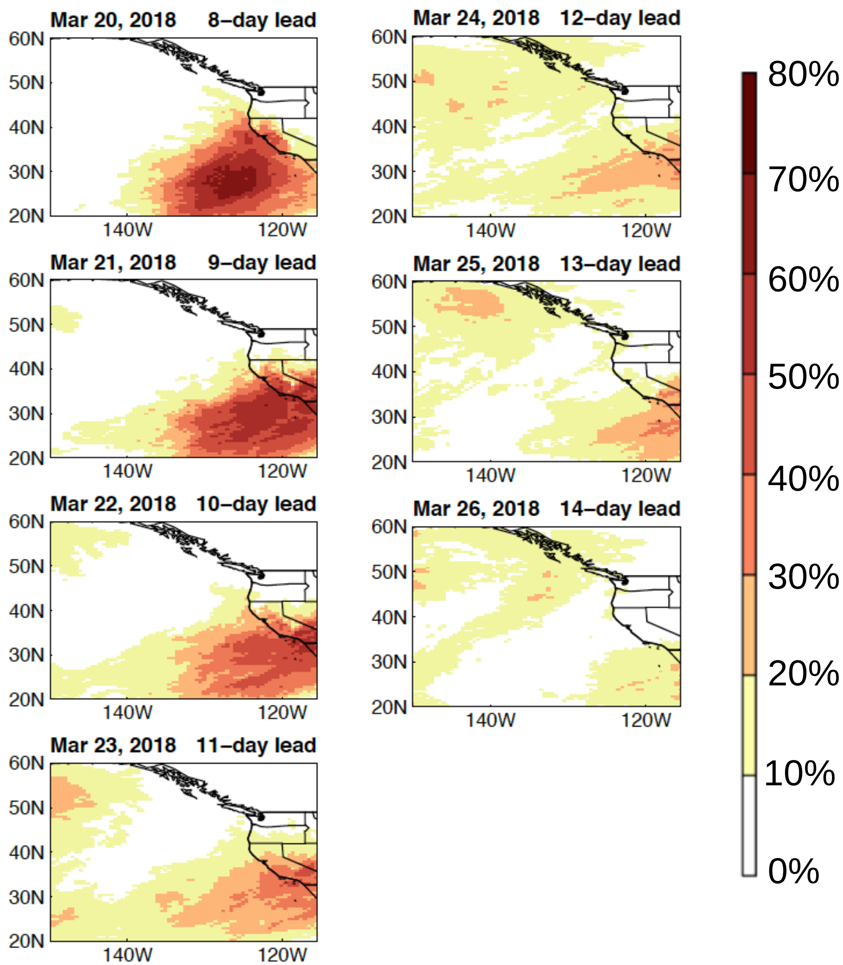
Contact: M. DeFlorio
(michael.deflorio@jpl.nasa.gov)

EXPERIMENTAL AR FORECAST

March 12, 2018 forecast: probability of AR occurrence during week-2



Week-2

(8-day to 14-day lead)

Experimental AR forecast issued on Monday, March 12, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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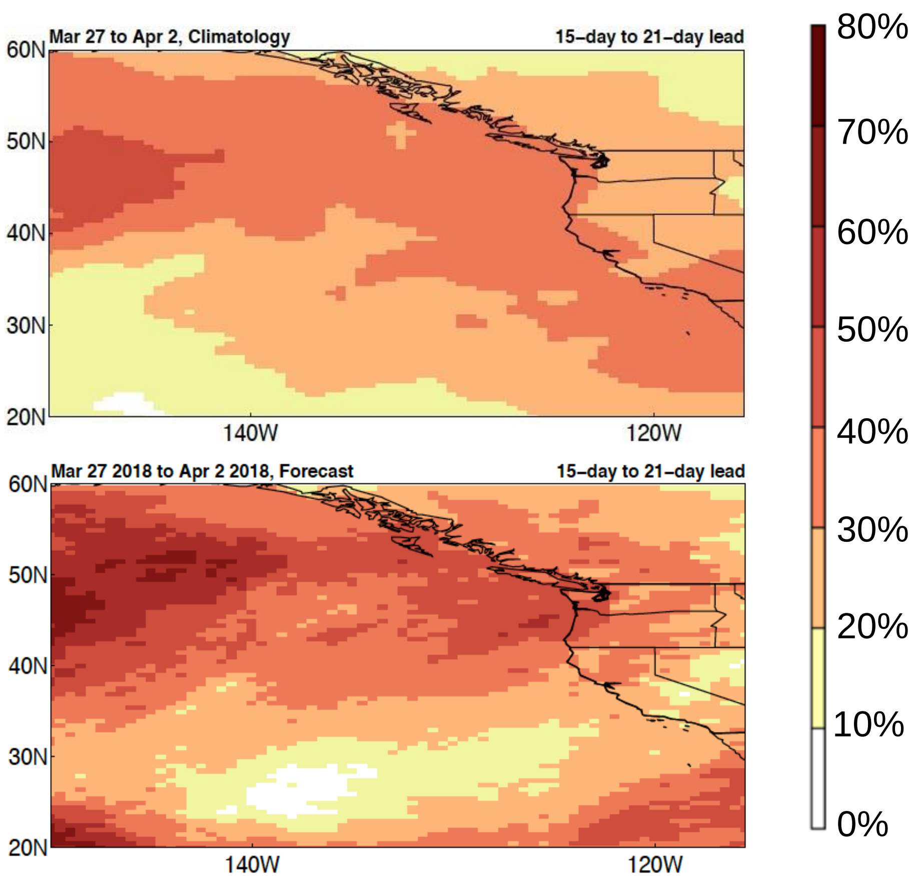
Contact: M. DeFlorio (michael.deflorio@jpl.nasa.gov)

EXPERIMENTAL AR FORECAST

March 12, 2018 forecast: probability of AR occurrence during week-3
(chance of an AR occurring at any time during week-3)



Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECMWF 1996-2015 data)
Bottom row: real-time forecast (ECMWF 51-member ensemble)

Experimental AR forecast issued on Monday, March 12, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

Jet Propulsion Laboratory
California Institute of Technology

Center for Western Weather and Water Extremes

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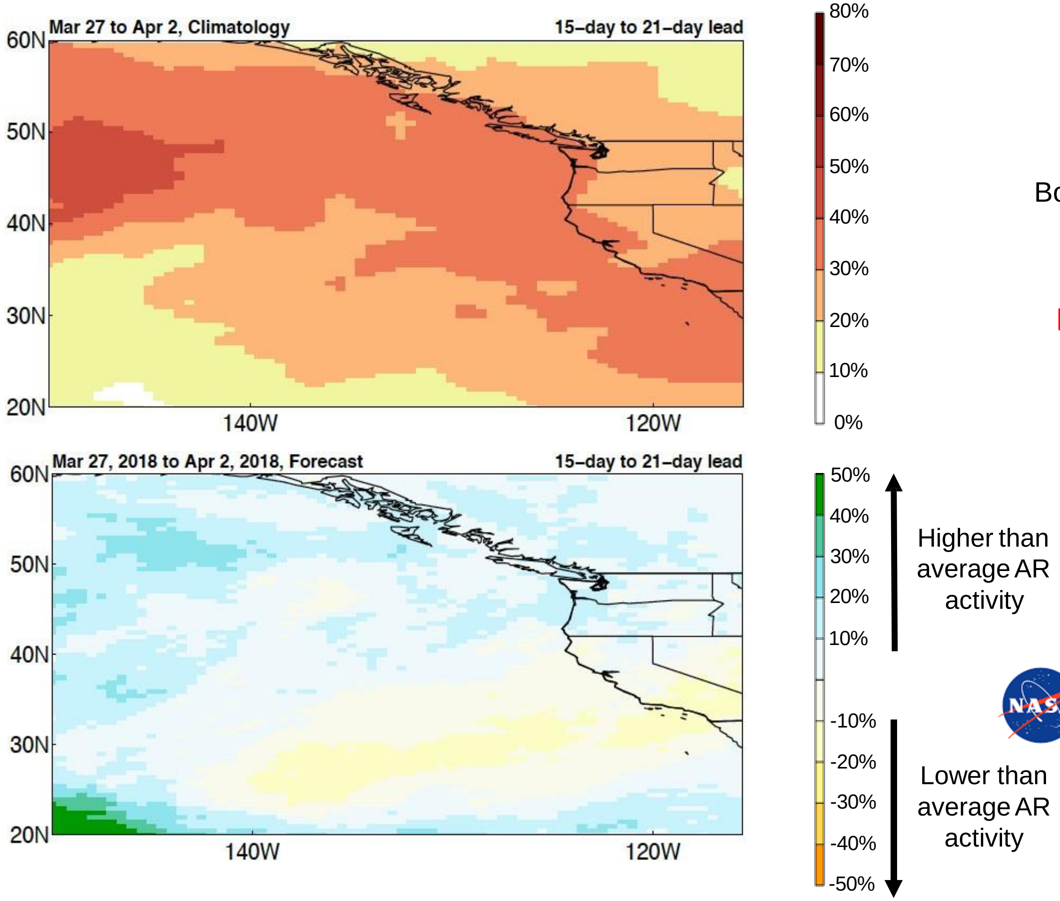
EXPERIMENTAL AR FORECAST

March 12, 2018 forecast: probability of AR occurrence during week-3
(chance of an AR occurring at any time during week-3)



Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECMWF 1996-2015 data)
Bottom row: real-time forecast minus climatology (ECMWF 51-member ensemble)

Experimental AR forecast issued on Monday, March 12, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

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Summary

- Atmospheric Rivers are a global phenomena that shape the Earth's climate, water and energy cycles, as well as account for regional weather and water extremes.
- We've developed a detection algorithm that can be *consistently* used on global "observations" (i.e. re-analyses), climate simulations and forecast models.
- Using this detection algorithm, we are developing model diagnostics and performance metrics, in conjunction with other observations (e.g. in-situ CalWater, satellite), to:
  - Identify and characterize hydrometeorological impacts from ARs
  - Evaluate model performance and identify weaknesses to guide model improvement.
  - Quantify forecast skill in a suite of operational S2S/weather prediction models.
  - Characterize projected 21^{ST} century changes in Atmospheric Rivers.
  - **Develop experimental week-3 AR activity forecast products.**

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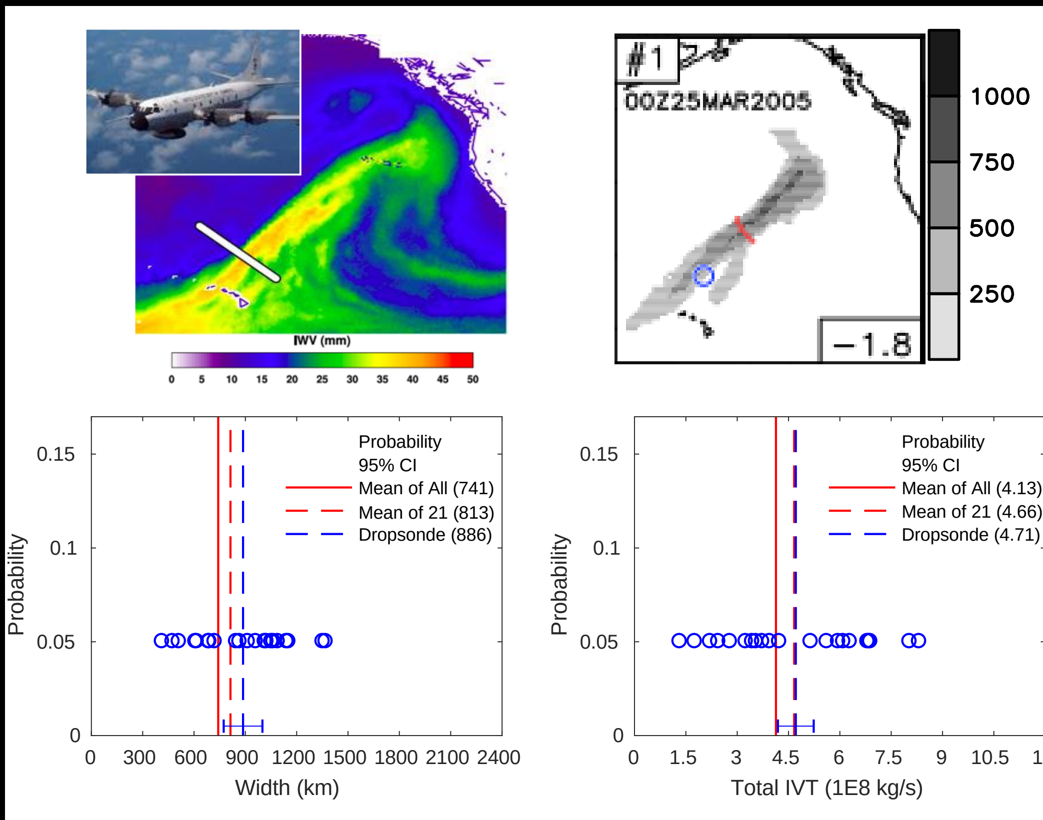
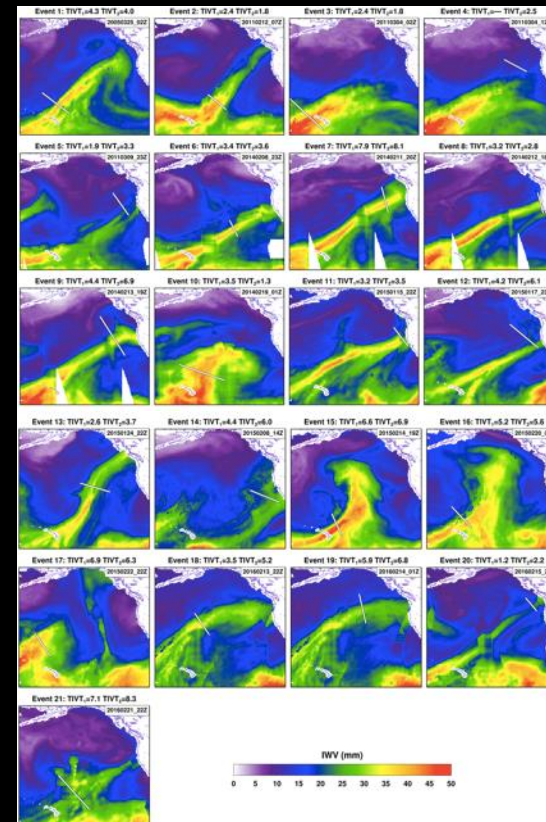
Algorithm Validation Support from CalWater

Guan, Waliser and Ralph (2018)





IVT Histograms Based On
5636 NE Pacific ARs from ERA-I
125-163W, 23-46N
Jan 15-Mar 25 1979-2016

Ralph et al. (2017)
21 AR Event Transects
4.7 +/- 1.9kg/s
Min 1.3; Max 8.3

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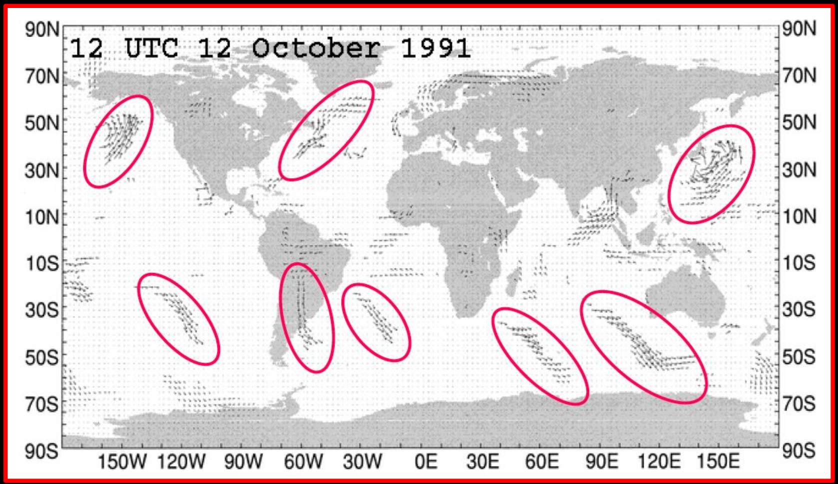
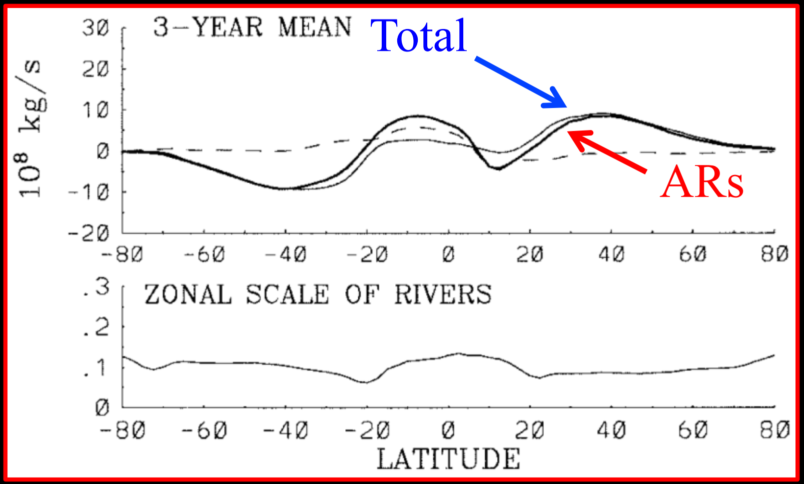
AR History: Poleward Moisture Transports

Influencing global Climate & Water Extremes





Over 90% of poleward moisture transport at midlatitudes is by ARs that take up only ~10% of the zonal circumference; Zhu and Newell (1998)

For discussion on connections between ARs, Tropical Moisture Exports (TMEs) and Warm Conveyor Belts (WCBs), see Cordeira (2015).

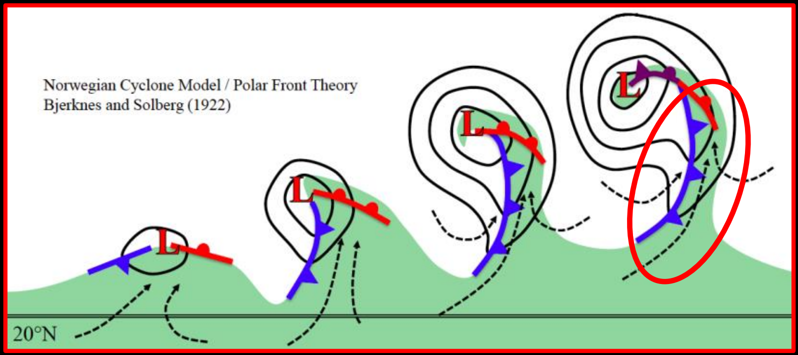


Figure courtesy J. Cordeira, Plymouth University

See AMS Glossary